PAN-PACIFIC ENTOMOLOGIST
69(1): 71–76, (1993)

EFFECTS OF TEMPERATURE ON DEVELOPMENT OF *BACTROCERA ZONATA* (SAUNDERS) (DIPTERA: TEPHRITIDAE)

ZAFAR QURESHI,[1] TALIB HUSSAIN,[1] JAMES R. CAREY,[2] AND ROBERT V. DOWELL[3]

[1]Atomic Energy Agricultural Research Centre, Tando Jam, Pakistan
[2]Department of Entomology, University of California, Davis, California 95616
[3]California Department of Food and Agriculture, 1220 N Street, Sacramento, California 95814

Abstract.—We measured the developmental times and survivorship of the immature stages of *Bactrocera zonata* (Saunders) and the longevity, preovipositional period and fecundity of adult flies at five temperatures between 15° C and 35° C. Egg hatch significantly increased with temperature from 15° C (51%) to 25° C (91.3%), and then decreased to zero at 35° C. No larvae completed development at 15° C or 35° C. Larval and pupal survival were greatest at 25° C, as were female fecundity (eggs laid) and fertility (% egg hatch). Developmental times for all stages were inversely related to temperature. Egg development was fastest at 25° C and 30° C, although larval, pupal and ovarian development were fastest at 30° C.

Key Words.—Insecta, *Bactrocera zonata,* temperature dependent development, immature survival, adult preovipositional period, fecundity and fertility

Temperature has been shown to be an important factor influencing the development of immature stages and ovaries of a number of economically important fruit flies (Tephritidae) (Moore 1960, Tsiropoulos 1972, Saeki et al. 1980, Okumura et al. 1981). Models describing the influence of temperature on developmental rate have been used to determine when to apply fruit fly control and eradication measures, and to determine the possible geographic distribution of various fruit fly species (Saeki et al. 1980, Meats 1981, Tassen et al. 1983).

Bactrocera zonata (Saunders), the peach fruit fly, is found in Egypt, Pakistan, Burma, India, Thailand, and Indonesia (Kapoor et al. 1980), where it attacks a range of fruit, including apple, guava, peach and pear (Nair 1975, Kapoor et al. 1980, Kapoor & Agarwal 1983). In India, it is as, or more, important a pest of commercial and dooryard crops than its better known cogenor *B. dorsalis* (Hendel), the oriental fruit fly (Kapoor & Agarwal 1983).

The recent discovery and successful eradication of several isolated infestations of *B. zonata* in California (Dowell 1988; Dowell & Gill 1989; RVD, unpublished data) have highlighted the need for data on the biology of this important fruit pest. Reported here are the effects of temperature on the development and survival of life stages of *B. zonata.*

MATERIALS AND METHODS

Rearing of Test Insect.—Guava infested with *Bactrocera zonata* were placed in wooden trays on sterilized sand moistened with distilled water until the larvae emerged. The resulting pupae were isolated and kept in wire cages (45 × 45 ×

55 cm) until adult emergence. This colony was reared through one generation to increase the number of flies before the experiments started. The rearing conditions were 25 ± 2° C, 65 ± 5% RH and a 14:10 LD cycle. The adults were provided water, protein hydrolysate (enzymatic) and sugar.

The larval diet was 100 g wheat shorts, 17 g brewer's yeast, 33 g sugar, 3.5 g agar, 0.5 g Nipagin, 20 ml HCl and 400 ml water. The wheat shorts, brewer's yeast, sugar and Nipagin were mixed together. The agar was dissolved in boiling water, and after cooling to 15° C it was mixed with the other ingredients, with the HCl added last. The mixture was blended for 2–3 minutes to a smooth consistency. The prepared medium had a pH of 4.5. The medium was poured into 15 petri dishes (9 cm diameter). Tissue paper was placed on the diet for seeding larvae (100 larvae per petri dish).

Temperature Studies.—We studied the effect of temperature on the life stages of *B. zonata* in Hotpack® programmable refrigerated incubators, each equipped with two 20 watt fluorescent lights and set at a 14:10 LD cycle. Test temperatures ranged from 15° C to 35° C in 5° increments. Fluctuation at each temperature was ±1° C. The procedures followed for testing the different stages are given in seriatum. Each test was replicated three times.

Eggs.—One hundred eggs obtained from the colony were placed on filter paper moistened with distilled water at each test temperature. After 24 h, each petri dish was examined hourly for egg hatch. After hatch was completed, unhatched eggs were counted and hatch percentage determined.

Larvae and Pupae.—One hundred neonate larvae were divided among three petri dishes kept at each test temperature. When the larvae reached third instar, the petri dishes were placed on sterilized sand in a covered enamel tray for pupation. Pupae were removed daily from the sand and kept in petri dishes until adult eclosion. Larval and pupal survival were computed from pupal recovery and adult emergence data respectively.

Adults.—The adults were sexed and 30 pairs were confined in each of three screen cages (25 × 25 × 35 cm) at each test temperature. Water, sugar and protein hydrolysate (enzymatic) were provided as food and mortality was recorded daily. An egging receptacle, a yellow plastic glass with fine holes in its sides and smeared internally with guava juice, was placed in each cage. The egging receptacle was replaced daily until all females had died. Eggs were removed daily from the receptacles and kept on moistened filter paper to determine percent hatch.

Following the above procedures, the effects of temperature on *B. zonata* development and survival were evaluated in four sets of experiments: (1) egg to adult stage, (2) larva to adult, (3) pupa to adult and (4) adults alone. This procedure allowed us to determine whether the flies acclimated to the colony rearing temperature. Analysis of variance tests were used to determine differences between developmental time, percent survival (arcsine squareroot of percent transformed) and adult fecundity data within and among experiments.

Results

Egg to Adult.—The effects of temperature on survival of *B. zonata* life stages are shown in Table 1. Egg hatch significantly increased with temperature from 15° C (51%) to 25° C (91.3%) and then decreased to zero at 35° C. No larvae completed development at 15° C or 35° C. Larval and pupal survival, and male

Table 1. Effect of temperature on survival of egg, larval, and pupal stages of *Bactrocera zonata* that were reared on artificial diet.

Test	°C	Stage specific survival (%)[a]		
		Egg	Larvae	Pupae
Egg to adult	15	51.00 [A]	—	—
	20	76.67 [B]	71.28 [C]	93.9 [B]
	25	91.33 [C]	93.78 [A]	97.66 [A]
	30	55.67 [C]	79.66 [B]	81.94 [C]
Larvae to adult[b]	20		62.67 [C]	88.86 [B]
	25		89.00 [A]	95.50 [A]
	30		72.33 [B]	88.93 [B]
Pupae to adult[b]	15			78.67 [C]
	20			92.33 [B]
	25			97.67 [A]
	30			95.00 [A]
	35			5.00 [D]

[a] Means followed in square brackets by different capital letters within each test differ at $P \leq 0.05$; $n = 100$ individuals per replicate, with three replicates conducted.

[b] Immature stages reared at 25° C prior to exposure to test temperature in latter two tests.

longevity were greatest at 25° C. Female longevity was the same at 20° C and 25° C. Longevity of both sexes was reduced by 59 to 74 days as the rearing temperature was increased from 25° C to 30° C. Female fecundity (eggs laid) and fertility (% egg hatch) were greatest at 25° C (Table 2).

Developmental times for all stages were inversely related to temperature (Table 3). Egg development was fastest at 25° C and 30° C, and larval, pupal and ovarian development were fastest at 30° C.

Larva to Adult.—With one exception, the trends described previously were seen when starting with neonate larvae instead of eggs: larval and pupal survival, and female fecundity and fertility were greatest at 25° C, no larvae completed development at 15° C or 35° C, no adults laid eggs at 30° C, adult longevity decreased between 25° C and 30° C, and developmental times were inversely related to temperature. In this test, however, adult longevity was inversely related to temperature with significant decreases at 25° C for both sexes (Tables 1–3).

Pupa to Adult.—Pupal survival was greatest at 25° C and 30° C but decreased at 35° C. No females laid eggs at 15° C, 30° C or 35° C and both fecundity and fertility were greatest at 25° C. Adult longevity significantly increased from 15° C to 25° C and then significantly decreased. As before, adult longevity decreased between 25° C and 30° C. Pupae completed development at all temperatures and developmental time was inversely related to temperature (Tables 1–3).

Adults.—The results starting with colony reared adults at each test temperature are similar to those starting with pupae: maximum female fecundity and fertility, and male longevity at 25° C. Female longevity was greatest at 20° C (Table 2). The preoviposition period ranged from 23.8 days at 20° C to 8.4 days at 30° C (Table 3).

Cross Test Comparisons.—Female fecundity and fertility were significantly reduced ($P < 0.01$) when pupae or adults were removed from the 25° C rearing colony and placed at 20° C when compared to females reared at 20° C starting as eggs or larvae. Adult survival at 30° C was significantly increased ($P < 0.01$) in

Table 2. Effect of temperature on female fecundity and fertility, and adult longevity of *Bactrocera zonata*.

Test	°C	Eggs per female	Percent egg hatch	Adult longevity (days)[a]	
				Female	Male
Egg to adult	20	177.62 [B]	53.33 [B]	78.94 [A]	62.26 [B]
	25	215.93 [A]	81.67 [A]	76.14 [A]	70.33 [A]
	30	—	—	4.70 [B]	3.77 [C]
Larvae to adult	20	175.58 [B]	57.00 [B]	70.08 [A]	61.56 [A]
	25	195.23 [A]	82.00 [A]	59.83 [B]	45.80 [B]
	30	—	—	3.10 [C]	2.97 [C]
Pupae to adult	15	—	—	19.33 [C]	17.33 [C]
	20	111.53 [B]	48.33 [B]	57.03 [B]	49.8 [B]
	25	202.7 [A]	81.30 [A]	72.80 [A]	62.7 [A]
	30	—	—	16.70 [C]	12.60 [D]
	35	—	—	8.60 [D]	6.37 [E]
Adult	15	—	—	12.30 [C]	9.80 [C]
	20	80.82 [B]	34.33 [B]	76.67 [A]	62.63 [A]
	25	172.27 [A]	89.67 [A]	67.6 [B]	66.10 [B]
	30	—	—	11.50 [C]	10.40 [B]
	35	—	—	5.03 [D]	4.30 [C]

[a] Means followed in square brackets by different capital letters within each test differ at $P \leq 0.05$; $n = 30$ pairs of flies per replicate with three replicates conducted.

flies held at 25° C until they were pupae or adults compared to those reared at 30° C starting as eggs or larvae.

Holding the previous developmental stages at 25° C had no effect on the developmental times or survival for *B. zonata* larvae or pupae held at 20° C or 30°

Table 3. Effect of temperature on duration of developmental stages of *Bactrocera zonata* that were reared on artificial diet.

Test	°C	Stage duration (days)[a]			
		Egg	Larvae	Pupae	Preoviposition
Egg to adult	15	2.90 [A]	—	—	
	20	1.79 [B]	13.5 [A]	18.7 [A]	
	25	1.02 [C]	6.1 [B]	11.6 [B]	
	30	1.02 [C]	5.4 [B]	6.2 [C]	
Larvae to adult	20		12.2 [A]	21.4 [A]	
	25		6.2 [B]	11.5 [B]	
	30		5.8 [C]	8.3 [C]	
Pupae to adult	15			30.0 [A]	
	20			18.0 [B]	
	25			10.3 [C]	
	30			7.4 [D]	
	35			4.1 [E]	
Adult	15				never
	20				23.8 [A]
	25				14.4 [B]
	30				8.4 [C]
	35				never

[a]Means followed in square brackets by different capital letters within each test differ at $P \leq 0.05$; $n = 100$ individuals per replicate, with three replicates conducted.

C (Table 1). This indicates that rearing the flies in colony at 25° C for the duration of this experiment caused no acclimation of the insects.

Discussion

Rearing temperature had a significant effect on the rate of *B. zonata* development. Like other fruit flies (Messenger & Flitters 1958, Pritchard 1978, Saeki et al. 1980, Fletcher & Kapatos 1981, Okumura et al. 1981), development is sigmoid up to a maximum of 26° C to 30° C and decreases thereafter. Although other factors including fruit moisture, ripeness, and variety, and larval crowding (Smith 1977, Tsitsipis & Abatzis 1980, Ibrahim & Rahman 1982, Carey et al. 1985) influence fruit fly developmental rate, temperature is the key factor in the field (Fletcher & Comins 1985).

Our data indicate that *B. zonata* can complete three to nine generations per year in the various parts of its range. This estimate compares favorably with other polyphagous fruit flies including *B. dorsalis* and *B. tryoni* (Froggatt) which have three to eight generations per year in various parts of their ranges (Saeki et al. 1980, Meats 1981).

Our results provide useful information for better handling of *B. zonata* in the laboratory. Mass rearing of fruit flies requires optimizing the rearing conditions for each stage to maximize turnover of production and quality of insect produced. Our data indicate that the optimum temperature for larval (25° C to 27° C) and pupal (20° C to 25° C) rearing are different because, aside from faster development, other parameters such as percent pupation, complete adult emergence from the puparia, and larval and pupal survival should also be considered. Temperature limits in a mass rearing system should be kept lower than optimum to avoid accidental overheating either from malfunctioning cooling systems or the build-up of metabolic heat.

Acknowledgment

This work was supported by a California Department of Food and Agriculture Research contract to the University of California.

Literature Cited

Carey, J. R., E. J. Harris & D. O. McInnis. 1985. Demography of a native strain of the melon fly, *Dacus cucurbitae* Coq. from Hawaii. Entomol. Exp. Appl., 38: 195–199.

Dowell, R. V. 1988. Exclusion, detection, and eradication of exotic fruit flies in California. *In* AliNiazee, M. T. (ed.). Ecology and management of economically important fruit flies. Agric. Exp. Stn., Oreg. State Univ., Spec. Rpt., 830.

Dowell, R. V. & R. Gill. 1989. Exotic invertebrates and their effects on California. Pan-Pacif. Entomol., 65: 132–145.

Fletcher, B. S. & H. Comins. 1985. The development and use of a computer simulation model to study the population dynamics of *Dacus oleae* and other fruit flies. pp. 561–575. *In* Atti XIV Cong. Naz. Hal. Entomol.

Fletcher, B. S. & E. T. Kapatos. 1981. Dispersal of the olive fly, *Dacus oleae* during the summer period on Corfu. Entomol. Exp. Appl., 29: 1–8.

Ibrahim, A. G. & M. D. A. Rahman. 1982. Laboratory studies on the effects of selected tropical fruits on the larvae of *Dacus dorsalis* Hendel. Pertanika, 5: 90–94.

Kapoor, V. C. & M. L. Agarwal. 1983. Fruit flies and their increasing host plants in India. pp. 252–267. *In* Cavalloro, R. (ed.). Fruit flies of economic importance. A. A. Balkema, Rotterdam.

Kapoor, V. C., D. E. Hardy, M. L. Agarwal & J. S. Grewal. 1980. Fruit fly (Diptera: Tephritidae) systematics of the Indian subcontinent. Export India Pub., Jullundur, India.

Meats, A. 1981. The bioclimatic potential of the Queensland fruit fly, *Dacus tryoni* in Australia. Proc. Ecol. Soc. Aust., 11: 151–163.

Messenger, P. S. & N. E. Flitters. 1958. Effect of constant temperature environments on the egg stage of three species of Hawaiian fruit flies. Ann. Entomol. Soc. Am., 51: 109–119.

Moore, I. 1960. A contribution to the ecology of the olive fly, *Dacus oleae* (Gmel.). Israel Agric. Res. Sta., Spec. Bull., 26.

Nair, M. R. G. K. 1975. Insects and mites of crops in India. Indian Council Agric. Res., New Delhi.

Okumura, M., T. Ide & S. Takagi. 1981. Studies on the effect of temperature on the development of the melon fly, *Dacus cucurbitae* Coq. Res. Bull. Plant Prot. Serv. Japan, 17: 51–56. [In Japanese with English abstract]

Pritchard, G. 1978. The estimation of natality in a fruit infesting insect (Diptera: Tephritidae). Can. J. Zool., 32: 353–361.

Saeki, S., M. Katayama & M. Okumura. 1980. Effect of temperature upon the development of the oriental fruit fly and its possible distribution in the mainland of Japan. Res. Bull. Plant Prot. Serv. Japan, 16: 73–76. [In Japanese with English abstract]

Smith, E. S. C. 1977. Studies on the biology and commodity control of the banana fly, *Dacus musae* (Tryon), in Papua New Guinea. Papua New Guinea Agric. J., 28: 47–56.

Tassen, R. L., T. K. Palmer, K. S. Hagen, A. Cheng, G. Feliciano & T. L. Blough. 1983. Mediterranean fruit fly life cycle estimates for the California eradication program. pp. 564–570. *In* Cavalloro, R. (ed.). Fruit flies of economic importance. A. A. Balkema, Rotterdam.

Tsiropoulos, G. 1972. Storage temperatures for eggs and pupae of the olive fly. J. Econ. Entomol. 65: 100–102.

Tsitsipis, J. A. & C. Abatzis. 1980. Relative humidity effects at 20°C on eggs of olive fly *Dacus oleae* (Diptera: Tephritidae) reared on artificial diet. Entomol. Exp. Appl., 28: 92–99.

Received 21 April 1992; accepted 13 September 1992.